UCRL-JC-131715
Preprint

Effective Cleanup at Lawrence Livermore National Laboratory: Innovative Technologies and Approaches

A. Lamarre,
K. Angleberger,
M. G. Brown

This paper was prepared for submittal to
Waste Management 99 Symposium
Tucson, AZ
February 28-March 4, 1999

November 12, 1998

Lawrence Livermore National Laboratory

EFFECTIVE CLEANUP AT LAWRENCE LIVERMORE NATIONAL LABORATORY: INNOVATIVE TECHNOLOGIES AND APPROACHES

Authors: Albert L. Lamarre, Lawrence Livermore National Laboratory; Kathy Angleberger, U.S. Dept of Energy; Michael G. Brown, U.S. Dept of Energy

ABSTRACT

At the Lawrence Livermore National Laboratory (LLNL) Livermore Site Superfund Site, ground water restoration efforts have been ongoing since 1989. Based on plans committed to by DOE in the Record of Decision (ROD) for the Site in 1992, ground water cleanup was predicted to take 61 years. What began as conventional pump and treat has evolved into an effective Engineered Plume Collapse strategy that employs a well-stocked tool box of remediation technologies, processes, and methodologies. This "tool box" approach has proven effective in solving the vexing problem of restoring the chlorinated volatile organic compound (CVOC) contaminated aquifers beneath the site. The Engineered Plume Collapse strategy has been used to hydraulically control the plumes on the western and southern boundaries of the site, doubled the pounds of CVOC removed from the subsurface compared to predictions in the ROD plans, and "collapsed" offsite plumes. The three major components of the Engineered Plume Collapse strategy are: (1) collection and use of historical and current chemical and hydrogeologic data to accurately identify areas of contamination in the subsurface and guide decisions about on-going remediation needs, (2) design, construction and operation of small, portable, and inexpensive ground water treatment units to implement pump and treat and collapse contaminant plumes back to their source areas, and (3) effective use of more energetic contaminant mass removal technologies in source areas, such as chemical oxidation, reductive dehalogenation, steam stripping, and electro-osmosis.

INTRODUCTION

Lawrence Livermore National Laboratory, located 45 miles east of San Francisco (Fig.1), has been conducting environmental restoration at its Livermore site since discovery of chlorinated volatile organic compounds in 1984. The site was listed on the Environmental Protection Agency's National Priorities List in 1987 and since then has been managed as a CERCLA site. The contaminated ground water is located in a complex system of alluvial aquifers. These aquifers were well characterized during the Remedial Investigation/Feasibility Study for determining the extent and potential fate and transport of the contaminants but were not as well understood for the purposes of removing contaminant mass. The original plan for restoring the ground water at LLNL was based on a rather simple concept of establishing hydraulic control of the ground water containing CVOCs (primarily trichloroethylene [TCE] and tetrachloroethylene [PCE]) above maximum contaminant levels (MCLs).

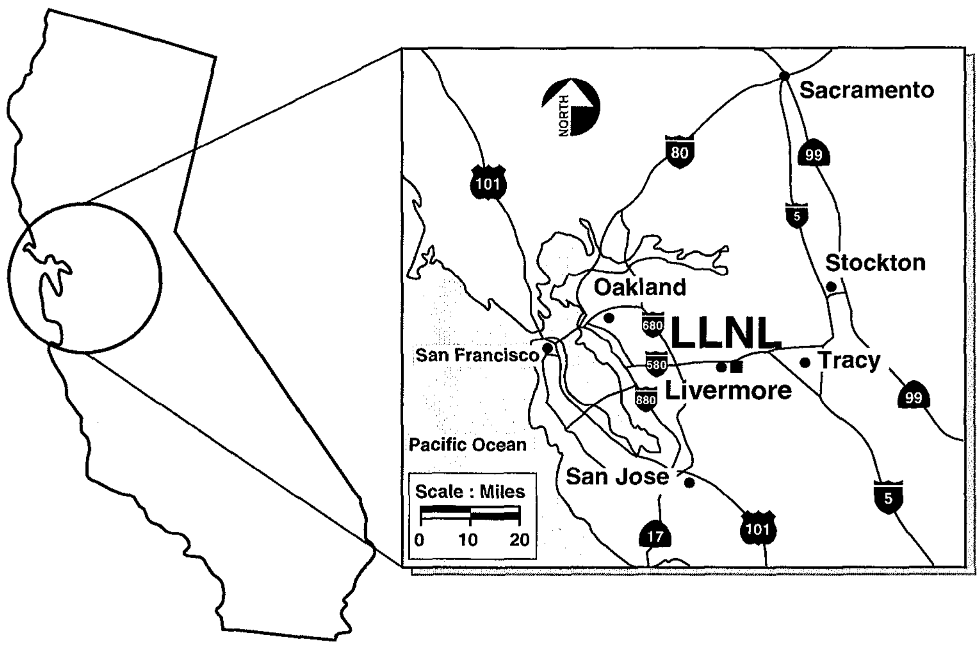


Fig. 1. Location of LLNL

DOE and LLNL recognized that although hydraulic control may effectively manage the risk of the site, it was not a technically feasible approach for achieving negotiated cleanup standards, and thus could not be used to eliminate DOE's long-term mortgage for the site. To revise its strategy for restoration of the site, LLNL first looked to the oil industry and started to view the contaminants as "product" to be recovered. This strategy required that contaminant mass and hydrogeological characterization data be used to "pinpoint" areas where contaminant concentrations were highest and where the hydrogeological characteristics could ensure optimal capture.

Second, real-time data were needed to be able to reassess extraction locations because the contaminant concentration maxima changed over time. The large, fixed treatment facilities originally envisioned in the ROD were not as cost effective in supporting the adaptive nature of this strategy and thus gave way to various types of inexpensive, portable treatment facilities.

The third key element to the success of this strategy is to prevent further "feeding" of contaminant mass to the plumes from the source areas. Contaminant release sites where high concentrations of contaminants are present as dense, non-aqueous phase liquids (DNAPLs) in coarse-grained sediments and/or in fine-grained sediments will continue to feed plumes if they are not removed or controlled. After successful remediation of distal plumes to prevent offsite impacts, the focus moves back to applying source remediation technologies in the sources.

Overall, this integrated “tool box” approach to cleanup comprises the Engineered Plume Collapse (EPC) strategy. EPC enhances the original ROD cleanup strategy from a simplified 2-D numerical model of the site to a detailed 3-D hydrogeochemical model of the site and consists of a systematic, aggressive, cleanup strategy comprised of four phases as shown on Fig. 2.

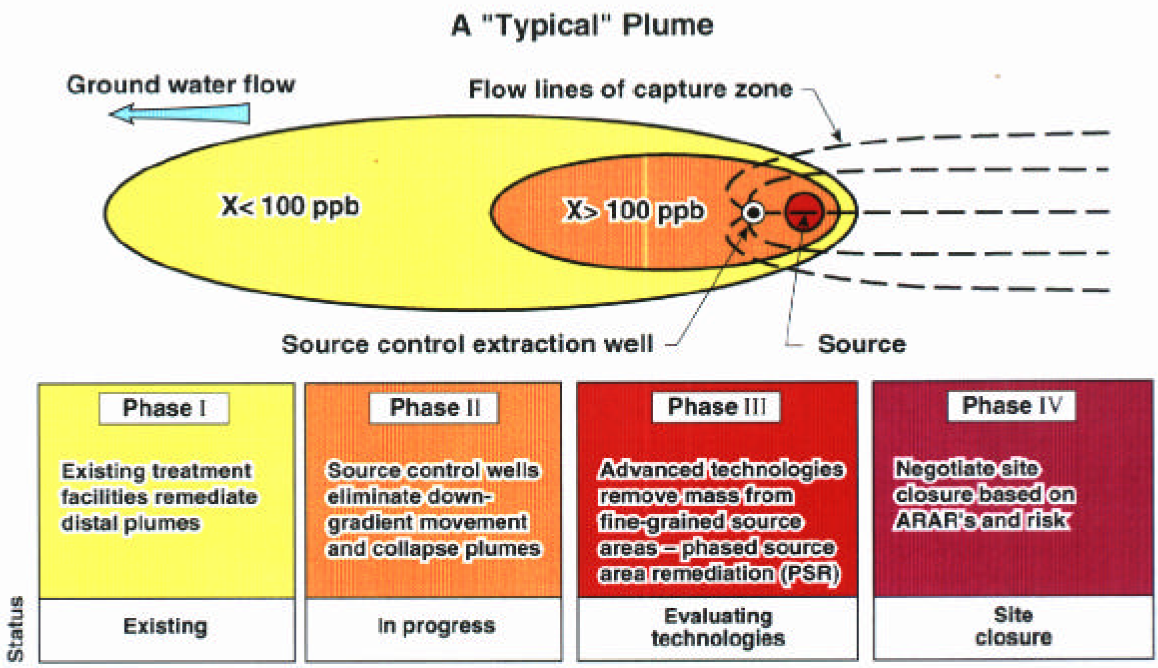


Fig. 2. Engineered Plume Collapse focuses the right remediation technologies at the right place at the right time.

Phase I-Target contamination within hydrostratigraphic units using a decision support system to map individual ground water contaminant plumes and their source areas based on site-specific geologic, geophysical, hydraulic, and chemical data.

Phase II-Analyze the data in Phase I to isolate source areas and hydraulically contain them to stop transport of contaminants to the distal parts of plumes. Collapse distal plumes back to their source areas using pump and treat technology with extraction wells positioned in high-permeability sediments to optimize mass removal and hydraulic capture.

Phase III-Apply conventional and advanced technologies to cleanup contaminated fine-grained source area sediments in a phased approach that ensures cost-effective remediation. Technologies currently being considered include variations of pump and treat strategy, soil vapor extraction, electro-osmosis, and thermal technologies such as dynamic steam stripping.

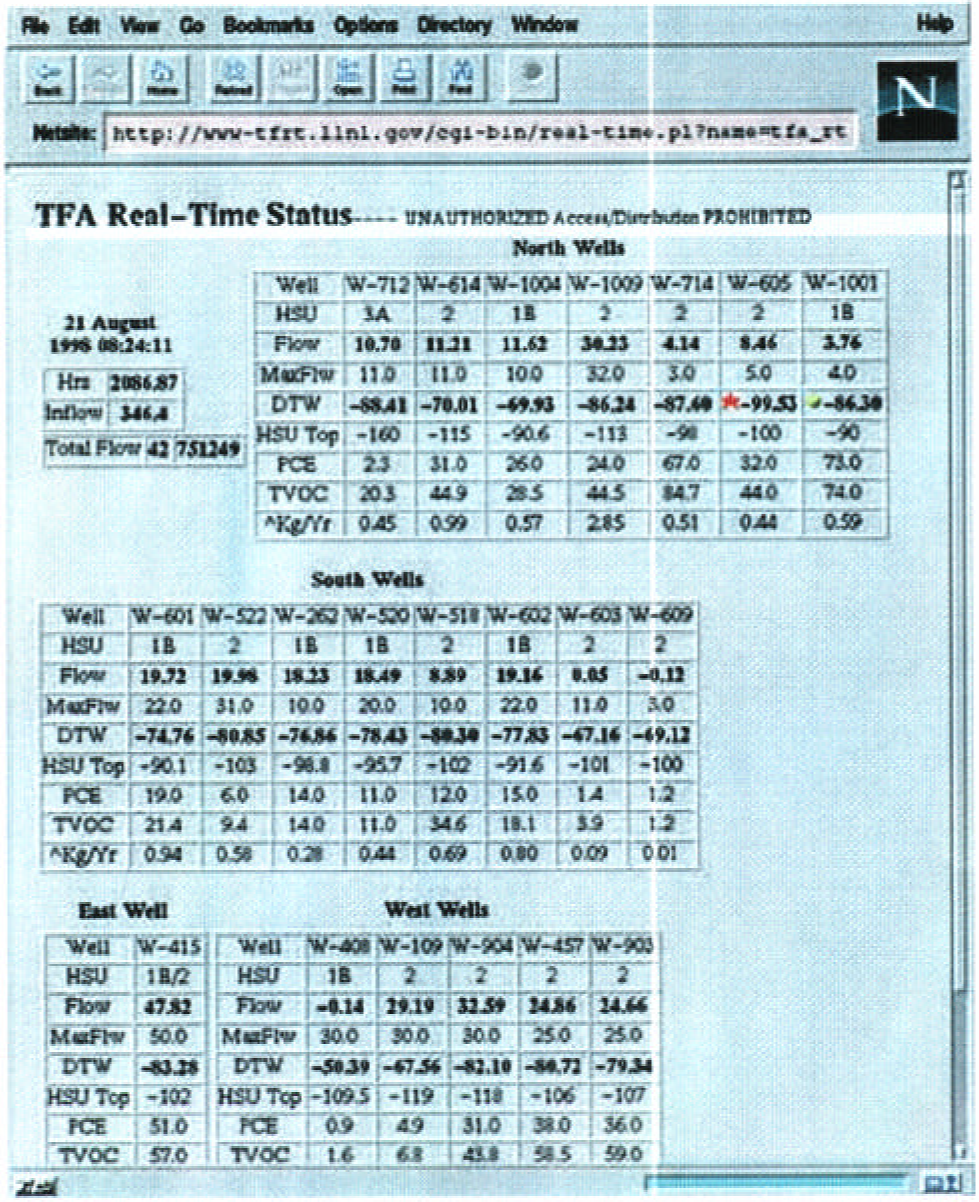
Phase IV-Negotiate Site Closure with the regulatory agencies based on a rigorous analysis of the health threats posed by any residual contamination remaining at the site. The decision will be made with full consideration of input provided by stakeholders.

Successful deployment of EPC is dependent upon three major elements: (1) use of accurate, real-time data as key to a decision support system, (2) design and construction of small, mobile and inexpensive ground water treatment units to implement pump and treat remediation where it works best, and (3) effective use of source area remediation technologies where applicable.

DECISION SUPPORT SYSTEM

To implement its remediation strategy and make real-time cleanup decisions, LLNL developed a broad based decision support system that is founded on an extensive database of hydrogeologic, chemical, and operational data. All data are stored in a relational database for rapid electronic retrieval and are available to scientists and engineers through a series of innovative web-based data access and manipulation tools. In addition to the traditional use of providing access to static documents, reports, images, and product and technology overviews, our webserver also provides project team members with dynamic access to project status by allowing form-based statistical processing, database access, and cost-estimating tools. Tools and data are served via a controlled access intranet. These new capabilities have demonstrated estimated annual cost savings of $500,000 and, for the first time, have made the enormous amount of collected data available to scientists on their desk top in a timely fashion and in a form immediately useful for analysis and interpretation.

Treatment facilities and wellfields are instrumented and data on flow rates and water levels are automatically entered into the database and are available in real-time to allow for frequent changes in extraction well flow rates to control water levels and hydraulic capture zones (Fig. 3). Quarterly chemical analyses from extraction and monitor wells are also automatically entered into the database and can be displayed using the web-based tools as tables, graphs or other plots in a matter of seconds, thus permitting decision-making on well shut downs or startups to optimize contaminant mass removal and control plume contours (Fig. 4). The ground water database is continuously updated such that scientists and engineers can target areas of high contamination and ensure hydraulic control of key plumes. Extraction wells can be added and removed from a dynamic extraction scheme based on application of plume tracking tools linked to the most current data.



File Edit View Go Bookmarks Options Directory Window Help

Netsite: http://www-tfrt.llnl.gov/cgi-bin/real-time.pl?name=tfa_rt

TFA Real-Time Status---- UNAUTHORIZED Access/Distribution PROHIBITED

21 August
1998 08:24:11

Hrs	2086.87
Inflow	346.4
Total Flow	42 751249

North Wells

Well	W-712	W-614	W-1004	W-1009	W-714	W-605	W-1001
HSU	3A	2	1B	2	2	2	1B
Flow	10.70	11.21	11.62	30.23	4.14	8.46	3.76
MaxFlw	11.0	11.0	10.0	32.0	3.0	5.0	4.0
DTW	-88.41	-70.01	-69.93	-86.24	-87.40	-99.53	-86.30
HSU Top	-160	-115	-90.6	-113	-98	-100	-90
PCE	2.3	31.0	26.0	24.0	67.0	32.0	73.0
TVOC	20.3	44.9	28.5	44.5	84.7	44.0	74.0
^Kg/Yr	0.45	0.99	0.57	2.85	0.51	0.44	0.59

South Wells

Well	W-601	W-522	W-262	W-520	W-518	W-602	W-603	W-609
HSU	1B	2	1B	1B	2	1B	2	2
Flow	19.72	19.98	18.23	18.49	8.89	19.16	0.05	-0.12
MaxFlw	22.0	31.0	10.0	20.0	10.0	22.0	11.0	3.0
DTW	-74.76	-80.85	-76.86	-78.43	-80.30	-77.83	-67.16	-69.12
HSU Top	-90.1	-103	-98.8	-95.7	-102	-91.6	-101	-100
PCE	19.0	6.0	14.0	11.0	12.0	15.0	1.4	1.2
TVOC	21.4	9.4	14.0	11.0	34.6	18.1	3.9	1.2
^Kg/Yr	0.94	0.58	0.28	0.44	0.69	0.80	0.09	0.01

East Well

Well	W-415
HSU	1B/2
Flow	47.82
MaxFlw	50.0
DTW	-83.28
HSU Top	-102
PCE	51.0
TVOC	57.0

West Wells

Well	W-408	W-109	W-904	W-457	W-903
HSU	1B	2	2	2	2
Flow	-0.14	29.19	32.59	24.86	24.66
MaxFlw	30.0	30.0	30.0	25.0	25.0
DTW	-50.39	-67.56	-82.10	-80.72	-79.34
HSU Top	-109.5	-119	-118	-106	-107
PCE	0.9	4.9	31.0	38.0	36.0
TVOC	1.6	6.8	43.8	58.5	59.0

Fig. 3. Example of report of real-time treatment facility status.

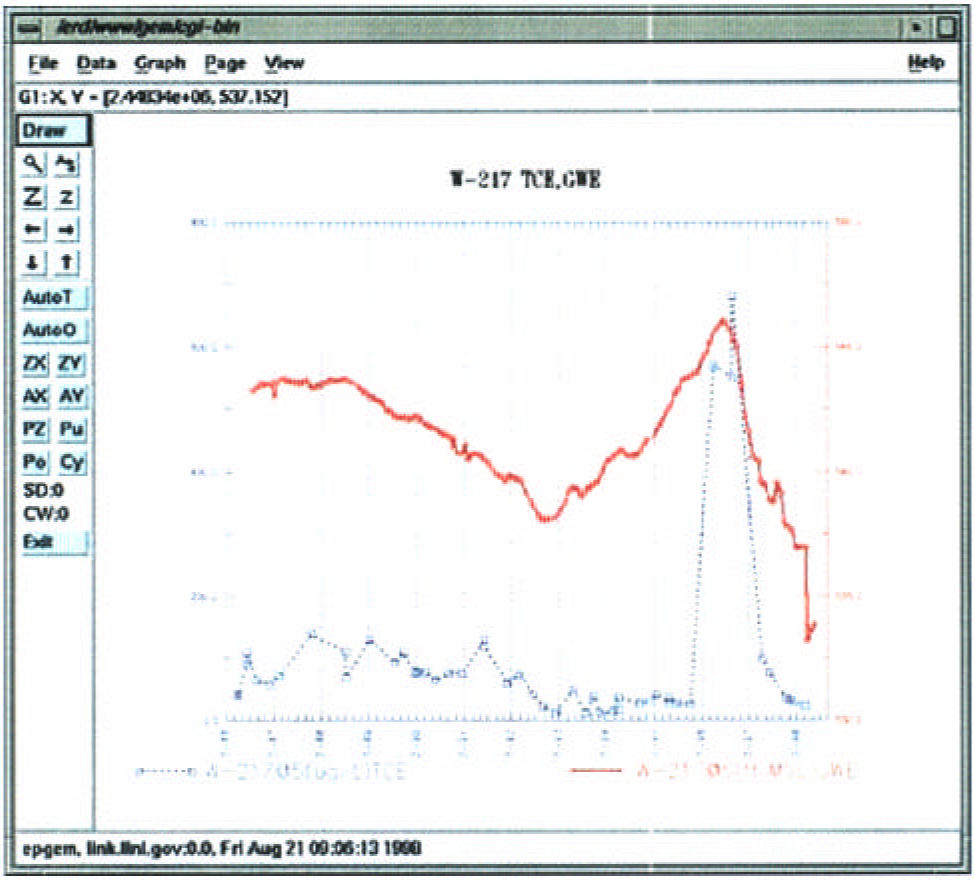


Fig. 4. Example of TCE and ground water elevation plot.

In addition, hydrogeologists have simplified the complex site geology into a more manageable conceptual model by employing hydrostratigraphic analysis. Hydrostratigraphic analysis, a technique used by oil and gas companies in their search for petroleum and natural gas, allows scientists to integrate chemical, hydraulic, and geologic data into a detailed, three-dimensional model of the subsurface. Implementing this technique is an effective management tool for making better decisions regarding ground water cleanup. These decisions include positioning and designing extraction and monitor wells, prioritizing the construction and phased startup of remediation systems, managing the extraction of subsurface contaminants, identifying the sources of past contaminant releases, and evaluating the effectiveness of remediation systems. This technique is also an effective visualization tool for presenting complex geologic and ground water remediation issues to regulatory agencies, stakeholders and the local community. In addition, hydrostratigraphic analysis forms the basis of two- and three-dimensional computer simulations of ground water contaminant transport using advanced physics codes to estimate cleanup times, costs, and design parameters.

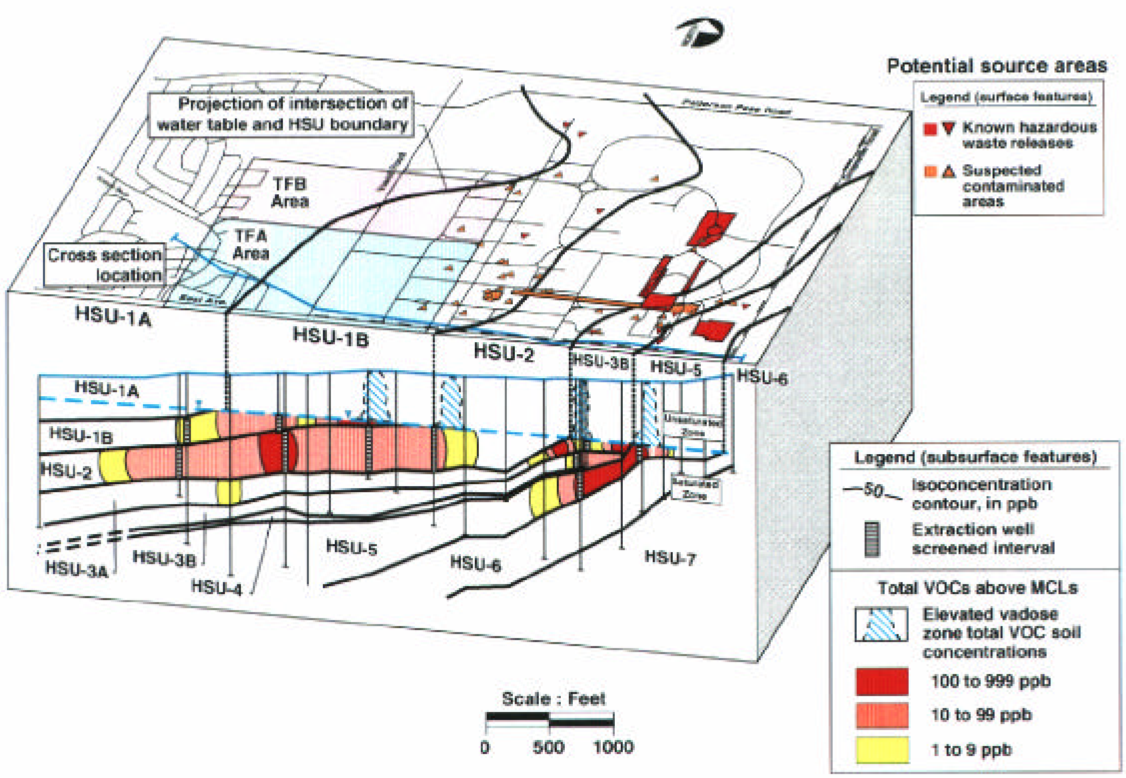


Fig. 5. Block diagram showing an example of hydrostratigraphic analysis as it is applied to the Livermore Site.

LOW COST AND EFFECTIVE GROUND WATER PUMP AND TREAT

To remove contaminants from permeable sediments, LLNL employs an adaptive pump and treat approach:

(1) A well-characterized site is essential to proper design of the remediaton system. To achieve this, extensive and detailed characterization of the site contaminant hydrogeology through geologic and geophysical logging of boreholes, monitoring of ground water chemistry in extraction and monitor wells, and computer modeling and visualization of subsurface conditions is performed.

(2) Drilling and construction of extraction and monitor wells based on geologic, geophysical and geochemical data is initiated. Operations at the extraction well fields and treatment facilities are modified whenever re-interpretation of subsurface conditions suggests that the time to attain cleanup goals can be reduced by such modifications. The most visible of these modifications occurs as new extraction wells are phased in.

(3) Operation of the remediation systems is continuously *modified* as monitoring information indicates that portions of the aquifers needing cleanup require different stresses. For instance, when an area between extraction wells becomes stagnant, we may either alter the pumping rates of nearby wells to ensure remediation of all parts of the contaminant plume, or install new extraction wells.

Since an adaptive ground water treatment approach requires flexible treatment capabilities, LLNL has developed ground water extraction and treatment systems that are portable, simple, and inexpensive. Large fixed treatment facilities with multiple pipelines from extraction wells were the baseline technology described in the Livermore Site ROD. However, these fixed facilities require that pipelines be moved or extended as ground water cleanup progresses. Engineers at LLNL determined that to successfully implement an adaptive remediation effort, the capital and operating/maintenance costs associated with these large facilities and their associated infrastructure was too high and that smaller, portable units could be employed instead. These portable treatment units are small, automated air stripping units that can be easily and inexpensively moved from location to location. They fit into 10 x 20-foot transportation containers that can be produced for less than $200,000 and have lower operating and maintenance costs than the larger facilities (Fig. 6). In addition, even smaller treatment units employing liquid phase carbon treatment and solar power are used in remote extraction well locations with small extraction flow rates and limited access to site utilities.

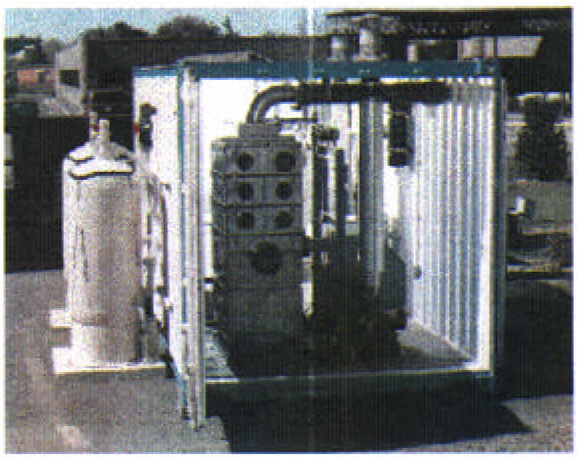


Fig. 6. LLNL-designed and constructed Portable Treatment Units allow project managers to cost-effectively modify extraction well and treatment facility networks to target changing VOC plume configurations.

Very high contaminant mass removal rates as compared to those projected in the Livermore Site ROD have confirmed that adaptive pump and treat is effective in rapidly removing volatile organic compounds from permeable sediments. Effectiveness of this approach is demonstrated by the time-series plots of PCE concentrations in the shallowest water-bearing zone (hydrostratigraphic unit 1B) at Treatment Facility Area A, shown in Fig. 7.

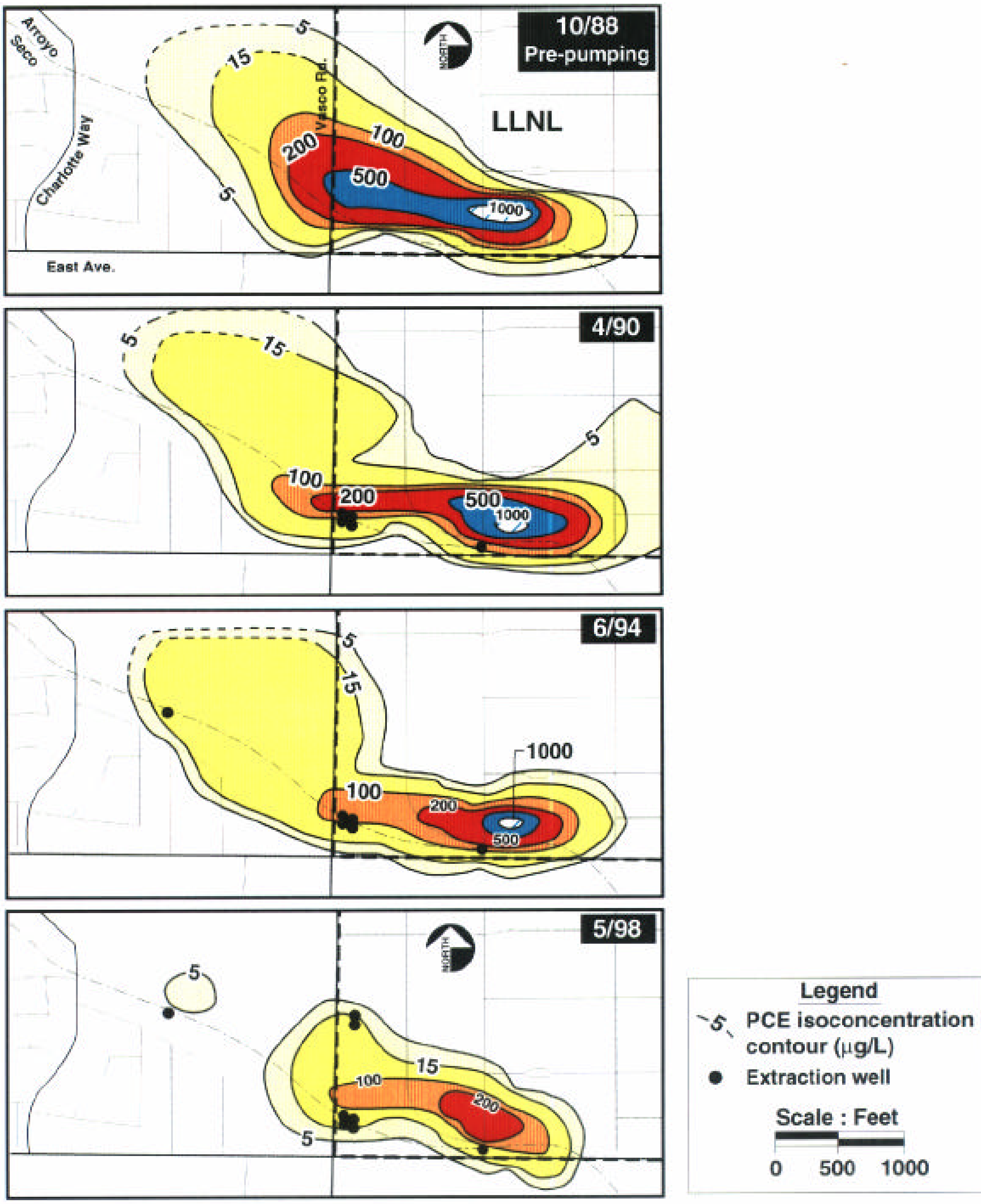


Fig. 7. Time-Series plot of PCE concentrations in hydrostratigraphic unit 1B at the Treatment Facility A Area

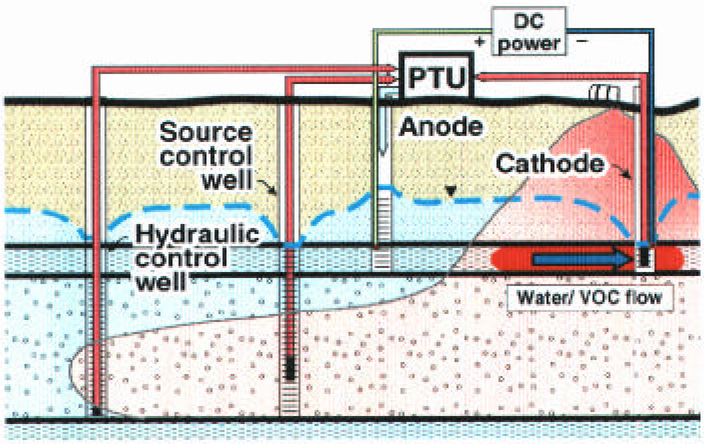
SOURCE AREA CLEANUP

The LLNL site is underlain by heterogeneous alluvial sediments of markedly varying permeabilities. Analysis of the Livermore Site shows over 30 CVOC plumes are contained within five hydrostratigraphic units. The contaminant plumes are large diffuse plumes emanating from relatively small volume source areas.

LLNL anticipates that CVOCs in less permeable sediments in the source areas will be more recalcitrant to cleanup and will require more aggressive and higher energy technologies. LLNL plans to employ a phased application of the higher-energy technologies to limit total remediation costs. As the off-site plumes are being contained, portable treatment units will be employed to control high contaminant concentration source areas and aggressively extract contaminant mass in permeable sediments around these source areas. This approach will collapse the plumes back to their sources.

Several technologies have shown promise for source area remediation. For DNAPLs, LLNL has tested food grade surfactants to mobilize contaminants into the ground water for more effective removal. However, the CVOC and surfactant contaminated ground water turned out to be very difficult to treat in conventional surface treatment facilities and thus the cost effectiveness of this technology is still in doubt for the Livermore Site. LLNL is already applying vapor extraction to remove CVOCs from the vadose zone so that transport from the vadose zone to the ground water will not occur. This high-energy technology removes CVOCs from the vadose zone rapidly and far more cost effectively than excavation or similar approaches. Because of the high degree of heterogeneity of the site, LLNL expects some low permeable areas will be best remediated by electro-osmosis and some areas by thermal techniques (Fig. 8). Electro-osmosis is the application of an electrical current to fine-grained geologic materials to drive ground water from pore spaces such that it and its dissolved contaminants can be removed via extraction wells. Electro-osmosis is an established geotechnical technique for dewatering that has been shown to be effective at other sites in removing contaminants from low permeability sediments. Electro-osmosis can be employed in low permeability materials while CVOC concentrations are still high in adjacent high permeability materials that are being actively remediated by pump and treat.

VOC removal with electro-osmosis



Dynamic steam stripping

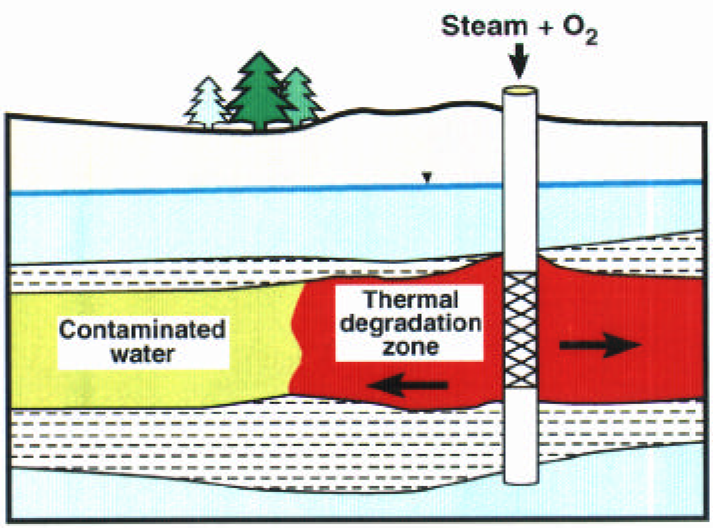


Fig. 8. LLNL is pursuing elecro-osmosis and dynamic steam stripping as technologies to remediate source areas.

Thermal techniques such as the application of dynamic underground steam stripping may be employed to recalcitrant areas. The steam can be used to mobilize contaminants in the subsurface for extraction or in some cases may be used to accelerate *in-situ* oxidation of CVOCs by a factor of 100 to 1000. The use of thermal techniques would follow significant reduction of CVOC concentrations in permeable sediments so that the more energetic thermal techniques will not spread the plumes. Thermal techniques have been shown to be effective for DNAPL or high concentration dissolved contaminants in permeable sediments where the plume can be surrounded by steam injection and nearby infrastructure will not be affected by elevated temperature. Thermal techniques may *also* be targeted at relatively thin areas of low permeability sediments.

In 1992-1993, LLNL successfully applied steam and electrical heating to remediate a petroleum hydrocarbon contaminated site at LLNL and received regulatory site closure. In addition, LLNL worked with Southern California Edison to remove 300,000 pounds of pentachlorophenol (a wood preservative) from the soil and ground water at a utility pole treatment facility in Visalia, California. Southern California Edison is working with the regulators to negotiate site closure for property transfer.

The phasing and application of these higher energy remediation technologies show promise for closing the Livermore site at the lowest total cost.

SUMMARY

In the final analysis, LLNL has used its scientific and engineering resources to design a ground water remediation program that uses the best data analysis and appropriate technologies to accelerate the cleanup process and meet the goals agreed to by DOE in the 1992 ROD.

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-18.